

# EXPANSION AND ORTHOGONALIZATION OF MEASURED MODES FOR STRUCTURE IDENTIFICATION

by

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## Abstract

Large flexible orbiting space structures, like the Space Station, cannot be assembled and tested on the ground due to their size and flexibility and due to the 1-g environment. Structure property identification and test/analysis correlation to validate math models of the structure must be performed from on-orbit tests. However, on-orbit measurements are typically made at only a few ( $p$ ) structure points for only a few ( $m$ ) dynamic response modes, while the finite element model to be validated will have many ( $n$ ) degrees of freedom (dofs). The math model of the structure is often reduced to  $p$  dofs for the purpose of test/analysis correlation, but physical relationships that contributed to development of the  $n$  dof model may be lost. Another option is to expand the measured mode shape vectors from  $p$  dofs to  $n$  dofs, as an estimate of the full mode shape vector. Also, full mode shape vectors are often required to be orthogonal with respect to the structure mass matrix. Subsequent orthogonalization of the expanded vectors is necessary or a simultaneous expansion/orthogonalization technique is required.

The purpose of the work this summer was to investigate a new simultaneous expansion/orthogonalization method in comparison with two previously published expansion methods and a widely used orthogonalization technique. Each expansion method uses data from an analytical model of the structure to complete the estimate of the mode shape vectors. Berman and Nagy [1] used "Guyan" expansion in their work with improving analytical models. In this method, modes are expanded one at a time, producing a set not orthogonal with respect to the mass matrix. Baruch and Bar Itzhack's [2] optimal orthogonalization procedure was used to subsequently adjust the expanded modes. A second expansion technique was presented by O'Callahan, Avitabile, and Reimer [3] and separately by Kammer [4]. Again, modes are expanded individually and orthogonalized after expansion with the same optimal technique as above. Finally, a simultaneous expansion/orthogonalization method was developed from the orthogonal Procrustes problem of computational mathematics [5]. In this method, modes are optimally expanded as a set and orthogonal with respect to the mass matrix as a result.

Two demonstration problems were selected for the comparison of the methods described above. The first problem is an 8 dof spring-mass problem first presented by Kabe [6]. This problem, shown in Figure 1, is used often in the literature to demonstrate system identification techniques. Several conditions were examined for each expansion method including the presence of errors in the measured data and in the analysis models. "Guyan" expansion with orthogonalization and the simultaneous expansion/orthogonalization method performed comparably, both slightly better than the second method.

As a second demonstration problem, data from tests of a laboratory scale model truss structure [7] was expanded for system identification. The test article, shown in Figure 2, exhibits characteristics expected for large space trusses (ie. closely-spaced frequencies, low damping, among others). Tests with a complete structure provided a correlated analysis model and the stiffness and mass matrices. Tests of various damaged

configurations (one member removed for each case) produced measured data for 6 modes at 14 dof locations. To date, the measured data is expanded and the quality of the resulting full modes is being studied. Optimal-update system identification methods are being applied to determine the damage location.

There are several areas where work needs to be done to advance the field of structural identification using expanded modes. Of prime interest is the selection of dofs to be measured in a test. Expansion and identification are expected to depend considerably on the measured subset. Also, the quality of the measured mode shape data and its effect on the methods discussed should be investigated.

#### References

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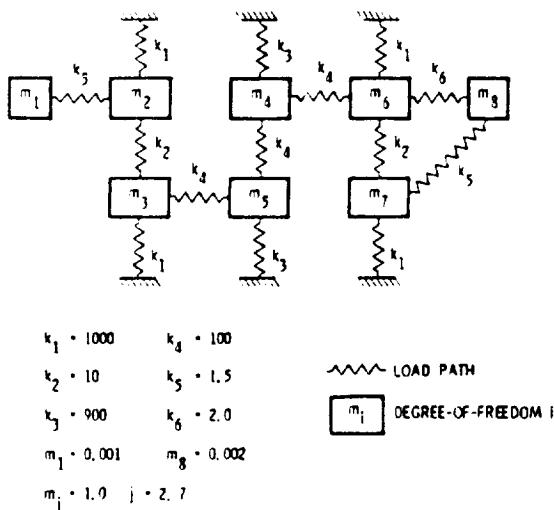


Fig. 1 Analytical test structure.

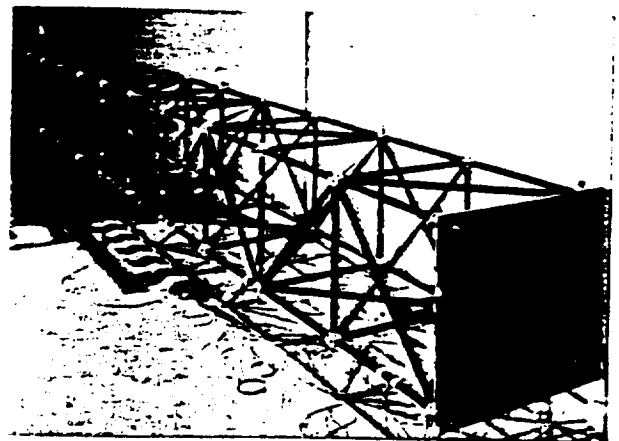


Figure 2. Ten-bay Generic Scale Model Truss Structure